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The Influence Of The Wastewater Drainage From The Las Vegas Valley on the Limnology of Boulder Basin, Lake Mead, Nevada-Arizona

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THE INFLUENCE OF WASTEWATER DRAINAGE FROM THE LAS VEGAS VALLEY ON THE LIMNOLOGY OF BOULDER BASIN, LAKE MEAD, NEVADA-ARIZONA

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ABSTRACT

Lake Mead, Colorado River, Arizona-Nevada, is one of the most heavily used reservoirs in the western United States, providing abundant recreational opportunities as well as downstream domestic and agricultural water for over 22 million users. Based on average nutrient levels and productivity, Lake Mead is classified as mildly mesotrophic. The interflow of the Colorado River dominates the limnology of much of the 106 km-long reservoir, and may still be identified at Hoover Dam under certain conditions. The lower basin of Lake Mead ending at Hoover Dam is known as Boulder Basin and is near the Las Vegas metropolitan area. Las Vegas Bay, which comprises the northwestern portion of Boulder Basin,receives all runoff including secondary and tertiary treated municipal sewage effluent from the Las Vegas Valley via Las Vegas Wash. The rapidly increasing population size of the Las Vegas Valley, and subsequent increases in inputs of point and non-point sources to Las Vegas Wash, has resulted in an increasing rate of eutrophication in Las Vegas Bay. Due to abundant nutrients, chlorophyll *a* concentrations during the months of June and July often exceed 100 $mg \cdot m^{-3}$, while secchi depth

decreases to less than 0.5 m. Within the first 4 km of Las Vegas Bay, extending away from the wash inflow, recovery from nutrient enrichment is dramatic. Secchi readings increase by over 5 m and chlorophyll *a* concentrations decrease by more than 90 percent. However, the influence of the density current plume from Las Vegas Wash, which is easily identified by its relatively high specific conductance and turbidity, can be observed to extend into Boulder Basin, and at times to Hoover Dam. The thickness, the distance to which it extends into the reservoir, and depth of the plume depend on the season of the year and corresponds to the degree of thermal stratification within the reservoir. Although not directly measured, limnological data suggest the potential for this plume to be entrained by municipal water intakes located at Saddle Island near the mouth of Las Vegas Bay. Outbreaks of cryptosporidiosis in Las Vegas have been shown to be associated with time periods when the plume was observed near the same depth as the intakes. Additionally, concentrations of bacteria and organic compounds are higher in the plume relative to the surrounding water.

INTRODUCTION

Lake Mead is a large mainstream Colorado River reservoir in the Mohave Desert, Arizona-Nevada (Fig. 1). Its lower end is 15 km east of Las Vegas, Nevada. Lake Mead, formed in 1935 following construction of Hoover Dam, is the largest reservoir in the United States by volume (36.7×10^9 m^3), and is second only to Lake Powell in terms of surface area (660 km^2) (Lara and Sanders 1970). At full pool (reservoir elevation 374 m above mean sea level (msl), Lake Mead extends 106 km from Black Canyon (Hoover Dam) to Pearce Ferry. Its greatest width is 15 km, and the highly irregular shoreline is 885 km in length. Lake Mead has four large

sub-basins: Boulder, Virgin, Temple, and Gregg. Between these Basins are four narrow canyons: Black, Boulder, Virgin, and Iceberg (Fig. 1).

Retention time in the reservoir is on average 3.9 years, depending on release and inflow patterns. The Colorado River contributes about 98 percent of the annual flow to Lake Mead; the remaining three inflows, the Virgin and Muddy Rivers and Las Vegas Wash, provide the remainder. Annual inflow via Las Vegas Wash was about 1.9×10^8 m^3 in 1995-96, providing the second highest volume of annual inflow to Lake Mead. Discharge from Hoover Dam is hypolimentic and occurs 83 m below the maximum operating level of 364 msl. Annual discharge is approximately 9×10^9 m^3. Annual withdrawal through the Southern Nevada Water System in Boulder Basin is presently about 0.55×10^9 m^3 (Roefer et al. 1996).

Overall, Lake Mead is mildly mesotrophic based upon several classification indices (Vollenweider 1970, Carlson 1977). As with other reservoirs, operations exert great influence on the water quality and ecology of the system (Thornton 1990). Unfortunately, the hydrodynamics of such large reservoirs are complex and not well understood. Each Basin within Lake Mead is ecologically unique, and therefore responds differently to the inflow outflow regime. Furthermore, the different sources of water entering Lake Mead, as in other reservoirs, often retain their identity and influence for substantial distances into the reservoir and do not necessarily mix completely with the rest of the water column (Ford 1990). This can lead to substantial underestimates of water retention time, transport rates, and fate of materials transported into the reservoir.

Boulder Basin is the most downstream Basin, and collects the combined flows from the reservoir's two main arms (Fig. 1). Additionally, it receives all drainage from the Las Vegas

Valley via Las Vegas Wash into Las Vegas Bay. This drainage includes both non-point surface and groundwater discharges, and treated effluent from all Clark County and municipal treatment facilities. Boulder Basin is about 15 km wide from Boulder Canyon to Hoover Dam (Black Canyon), and it is about 18 km from the confluence of Las Vegas Wash to Hoover Dam. The historical Colorado River channel lies along the eastern side of the Basin.

The morphology and hydrodynamics of Lake Mead are such that the nutrient loading, which continues to steadily increase due to increasing wastewater discharge through Las Vegas Wash, is confined to Boulder Basin (Paulson and Baker 1981, Prentki and Paulson 1983). This situation is unusual for a reservoir since it is a reversal of the normal upstream to downstream decrease in the pattern of productivity (Kimmel et al. 1990). As a result of abundant nutrient input into Las Vegas Bay, it was not uncommon to measure chlorophyll *a* concentrations greater than 100 $mg \cdot m^{-3}$, and to have secchi readings less than 0.5 m in the inner Bay (J. LaBounty, unpublished data). Highest measured chlorophyll *a* concentrations in the inner Bay of 330 $mg \cdot m^{-3}$ in August 1993 (blue-green algae bloom), and 397 $mg \cdot m^{-3}$ in December 1996 (cryptophyte algae bloom). Recovery from nutrient enrichment in the photic zone is rapid. Within the first 4 km from the wash inflow, secchi transparency increases over 5 m and there is a 90 percent reduction in the amount of chlorophyll *a* (J. LaBounty, unpublished data).

The results reported here are part of the present ongoing investigations of the limnology of Boulder Basin which began in mid-1990. The principal objective of this paper is to provide a seasonal description of the flow of water from Las Vegas Wash as it moves into Las Vegas Bay and Boulder Basin, and to discuss these findings relative to the municipal water supply of the Las

Vegas Valley which is withdrawn from Boulder Basin at Saddle Island just south of the mouth of Las Vegas Bay at Saddle Island.

METHODS AND MATERIALS

Limnological sampling was done at a series of 10 sites (LV01-LV17) in a linear transect from the Las Vegas Wash inflow (LV01) to the immediate forebay of Hoover Dam (LV17) (Fig. 1). All sites were located at the deepest point of the historical stream channel as initially determined with a depth finder. Sites were sampled a minimum of once monthly, October through April, and twice monthly, May through September. At each site, the limnological profile included measurement from surface to bottom for temperature, dissolved oxygen, pH, specific conductance, and turbidity. Data were collected at 1 m intervals at least through the thermocline, then 2-5 m thereafter depending on uniformity of the water column. Profile data were collected using an H20 Sonde unit connected to a Surveyor 3 data recorder (Hydrolab Corporation ®). Samples for analysis of nitrate, ammonia, and ortho-phosphate were collected from four depths at each site at the surface, 1 m, 3 m, and from the depth of the Las Vegas Wash plume as indicated by the highest specific conductance reading, which varied with the depth of the plume. Sample analyses were performed by the Bureau of Reclamation Soil and Water Analysis Laboratory in Boulder City, Nevada, and followed that of Standard Methods for the Examination of Water and Wastewater (APHA 1992). All sampling was completed between the hours of 0800 and 1300 in a sequence beginning at LV01 and ending at LV17. Additionally, one complete set of profile data were collected for a series of sites along the Colorado River channel from Grand Wash at the upper end of Lake Mead to Hoover Dam, to illustrate patterns of interflow generated

by the Colorado River. Processing of data and development of graphical presentations was done using both Quattro Pro 7 (Corel ®) and Surfer (Golden Software ®) software packages.

RESULTS

Las Vegas Wash Inflow

SEASONAL DYNAMICS

The fate of water entering Las Vegas Bay can be tracked both by its high conductivity signature, or in a similar manner because of its higher turbidity relative to the main body of Boulder Basin (Fig. 2). This study focused on conductivity because of its reliability and ease of measurement. Beginning in January, water flowing into the Bay from Las Vegas Wash is warmer than that of the inner Las Vegas Bay (20 °C vs. 14 °C) (Roline and Sartoris 1996). Also, conductivity is much higher in the Wash than in the lake (2500 uS·cm^{-2} vs. 1000 uS·cm^{-2}). There is some mixing in the inner Bay as indicated by its higher overall conductivity versus that of the outer Bay. However, the plume retains its identity as an underflow for about 4 km into Boulder Basin in January (Fig. 3a). This underflow follows the thalweg of the historical stream channel of Las Vegas Creek (now referred to as Las Vegas Wash) until an equilibrium depth is reached below, which lake water, due to cooler temperatures, is denser than plume water. This occurs at a depth of 40 to 60 m in late winter. At this lake depth, the plume then continues into the Basin as interflow, being supported by the denser water of the hypolimnion until it has dispersed and mixed to the point it can no-longer be detected by our standard measurements.

In early spring, the plume elevates into the water column existing as an underflow for a shorter and shorter distance before becoming interflow (Fig. 3 a-f). This change is a function of both stratification developing in the reservoir and the warming of inflowing water from Las

Vegas Wash. Conductivity remains relatively stable throughout the year, however, the inflow water temperatures increase from 20° to nearly 28 °C by mid-summer (Roline and Sartoris 1996). Although Las Vegas Wash water is warmer then lake water, it still tends to underflow due to its higher density caused by salinity. In both late spring and early fall, water temperature of the plume may be 1-2°C higher than that of surface waters for a distance of 2-3 km (Figs. 3b,f temperature profiles). By early summer, the plume is located at its shallowest depth of the year as a result of increasing temperature of the inflow and the relatively shallow thermocline in the Bay. As the thermocline strengthens, the plume flow is tightly bound to the thermocline. It is constrained from below by denser cold water, and from above by the less dense warm surface waters. Conductivity gradients identifying the plume are sharpest at this time. Depending on conditions, this plume may exist intact for 8 to 10 km from the inflow of Las Vegas Wash, and on occasion can be identified nearly to Hoover Dam. By late summer, the plume again begins to sink as the thermocline deepens and the inflowing water cools. Again, even though inflowing water is warmer than the water in Las Vegas Bay, it still sinks due to its higher conductivity. This is most easily observed in November when the warmest water is located at the bottom. Table 1 summarizes the general seasonal position and extent of the plume based on data from 1991-1996.

Dissolved oxygen and pH profiles are both strongly influenced by stratification and temperature (Fig. 3 a-f). Shifts in pH tend to closely mimic those of dissolved oxygen. Dissolved oxygen levels decrease in the hypolimnion as stratification increases and mixing is reduced. Oxygen depletion in the hypolimnion occurs over the course of the summer, and is greatest during the months of August and September. Depletion is greatest in the inner Bay with

dissolved oxygen levels gradually rising with distance. This pattern is likely due to oxygen demand associated with processes breaking down allochthonous organic material introduced via the Wash.

LONG TERM DYNAMICS

Development of thermal stratification in Boulder Basin follows a seasonally predictable pattern. The formation of the thermocline in turn depicts where the Las Vegas Wash inflow plume is located within the water column. Based upon seasonal temperature data over the past five years, the main body of Boulder Basin has not completely turned over on a yearly basis (Fig. 4). The last time we recorded that the lake turned over completely was in 1991. Areas of the reservoir shallower than 70 m do turnover on annual basis from November through sometime in January. For example, areas such as LV14 (Fig. 5), where depths are somewhat over 100 ms, the pattern is similar to that at Hoover Dam. Areas of the Basin, (i.e., in and around LV05 (Fig 6), where the depth is about 20 m, undergo complete mixing.

LOADING

Total nitrogen is considerably higher in the plume of water entering from Las Vegas Wash, and is an indication of higher inorganic and organic load of Wash inflow relative to the main body of Lake Mead (Table 2). Nitrogen concentrations (calculated as ammonia plus nitrate concentrations) were two to five times higher in the plume than in any other portion of the water column. Occasionally, levels would approach 10 times that of the adjacent water column. Concentrations decreased in a consistent manner with distance from the inflow source. At LV14, nitrogen concentration in the plume were 20-30 percent higher than the surrounding water column.

Biological productivity in portions of Boulder Basin is therefore driven by nutrients input from Las Vegas Wash. Additionally, concentrations of bacteria and unknown soluble organic compounds are much higher in the plume than in the surrounding water column (Personal Communication Mr. Alan Simms and Ms. Peggy Roefer, Southern Nevada Water Systems, Las Vegas; Dr. Kevin Kelly, USBR Environmental Chemistry Research Group, Denver)

Colorado River Inflow

During the months of August and September 1996, a plume of low conductivity water was present in the metalimnion, just under the thermocline extending across Boulder Basin. It extended well into Las Vegas Bay (Fig. 3 d-e). This was the Colorado River interflow retaining its identity through the entire 183 km length of the reservoir (Fig. 7). Momentum to this interflow was provided by the experimental flood flows from Glen Canyon Dam in late April and early May. Figure 7 depicts data collected from a longitudinal series of profiles sampled along the entire reservoir from Grand Wash to Hoover Dam. The river enters Lake Mead as hypolimnetic interflow in the summer, and depending on conditions, retains much of its integrity. The Colorado River plume exists as interflow through the entire length of the reservoir in August. Such an occurrence does not occur yearly, however, it was seen in both 1995 and 1996 (as represented by the two low conductivity centers at 20 to 30 m during summer months Fig. 5), but not in 1993 or 1994. The magnitude of the interflow from the Colorado River is directly related to the amount of water entering Lake Mead from upstream (observations USGS inflow data). Flows in both 1995 and 1996 were near average. Those of the previous four or five years were below average. We did not note any presence of a Colorado River interflow during those years.

Long-term trends for Boulder Basin indicate gradual shifts in water column conductivity due to the Colorado River. Figure 4 indicates a gradual increase in conductivity in Boulder Basin from 1991 through 1994. However, beginning in 1995 (Fig. 5), there has been a gradual decrease in conductivity, likely related to the larger volume of water being input to Lake Mead as a result of increased inflows. This indicates the dilution effects of the Colorado River inflow on the total dissolved solid concentration.

In contrast to the Las Vegas Wash plume, water sampled from the Colorado intrusion, as indicated by lower conductivity (Fig. 3 d,e), tends to contain lower levels of nitrogen then the surrounding water column.

Summary

Water entering Las Vegas Bay from Las Vegas Wash can be tracked by the high conductivity signature acquired as a result of saline groundwater inputs prior to its entering Las Vegas Bay. Water entering Las Vegas Bay exists as underflow, interflow, localized overflow, or is almost completely disassociated depending on the degree of thermal stratification, and on the conductivity and temperature of inflowing water (Fig. 3 a-e). Some mixing occurs in the inner Bay during all seasons of the year as indicated by higher conductivity (Fig. 3 a-e). However, the Las Vegas Wash plume retains its identity well into the reservoir. The intrusion of Colorado River water can also be identified as extending at times well into Boulder Basin.

DISCUSSION

Density Currents - Temperature and Conductance

Investigations of density currents in Lake Mead were first done beginning in June 1937 (Bureau of Reclamation 1941, 1947). In 1967, interflow patterns were investigated in Boulder Basin and reported in Sartoris and Hoffman (1971). More recently, Paulson and Baker (1981), Prentki and Paulson (1983), and Kimmel et al. (1990) discuss the consequences of interflow,

including that from the Colorado River, to primary production in Lake Mead. Water entering Las Vegas Bay from Las Vegas Wash exists as overflow, underflow, and/or interflow depending on the time of year, climatic conditions, and inflow patterns. The intrusion moves through the reservoir at a position where it and reservoir water densities are similar. Penetration into the lake depends on whether or not the flow is sustained or cut off as a result of mixing in the inner Bay, which is a seasonally dependent phenomena. When flow is cut off, interflow quickly stalls, completely dispersing or becoming both an underflow and overflow until a new position is established (Ford 1990). Similar observations can be made for the Colorado River intrusion, although its effects on Boulder Basin are more dependent upon average annual inflows and outflows to Lake Mead. Stratification, however, drives the overall pattern in both cases.

The development of stratification involves differences in density, and is influenced both by temperature and total dissolved solids (correlated to specific conductance). Warmer water is more stable since there is greater density change in warmer water than in cold. For example, it takes about 30 times as much energy to completely mix the same volumes of 24 to 25°C water as it takes to mix the same volumes of water at 4 to 5°C (Horne and Goldman 1994). To indicate the dominance of thermal structure in defining stratification, consider that at 25°C it takes approximately 330 $mg \cdot L^{-1}$ of TDS concentration to equal the density difference by a 1°C temperature change (Ford 1990). However, at temperatures of 10°C or less, concentrations of less than 30 $mg \cdot L^{-1}$ effect a similar change. It is therefore the combination of temperature changes and salinity that depict the location and fate of the Las Vegas Wash plume as it enters Las Vegas Bay.

While climate is a factor and does influence the seasonal nature of the Boulder Basin's ecology, its effects are relatively predictable from season to season (Table 1) and from year to year. The general pattern from 1990 through 1996 was the following: surface temperatures ranged from about 14°C in December and early January to over 30°C in August, a strong thermocline developed seasonally and ranged in depth from 15 m in early summer to 30 m in late summer as the epilimnion gained heat, deep hypolimnetic temperatures remained near 12°C year round, and although the thermocline, in a textbook sense, essentially disappeared each fall, a gradual temperature gradient remained.

During the coolest time of year, the 2°C difference in water temperature from surface to bottom, combined with the maximum reservoir depth (150 m), acts to limit complete mixing of the water column. Therefore, under normal or below normal runoff conditions, complete turnover of Lake Mead rarely occurs. However, mixing does occur each year for about a two month period of time to a depth of 60 to 70 m. Thus, only shallower Bays and those portions of the lake shallower than 60 to 70 m undergo complete mixing. A substantial pool of hypolimnetic nutrients remains permanently unavailable to epilimnetic production in the main Basin.

As a result of seasonal patterns of stratification, the position of the Las Vegas Wash intrusion is predictable since it is dependent upon thermal structure of the Basin. During cooler periods (late November to early January), the thermocline gradually weakens as the lake cools and the epilimnion mixes to deeper depths. As a result, the intrusion of water extending out from Las Vegas Wash also exists at deeper depths. By December, the location of the intrusion deepens to 40 to 60 m, and although its presence may be noted as far from the inflow as LV14

(6 km), the intrusion is relatively unstable and may at times be completely dissipated. January and February show similar trends. The plume continues to gradually deepen, and it will often quickly dissipate.

There are several possible explanations for the plume's instability at this time of the year. Fischer and Smith (1983) described the influence of weather as a factor when they performed dye injection investigations in late April and early May 1980, and again in mid-August 1980. Weather continues to play a large role, especially during the late winter and early spring. Epilimnetic temperatures in the early winter are much cooler (> 3 °C) than the inflowing Wash water, and may tend to promote a greater degree of epilimnetic mixing, particularly at times of high sustained winds. Overall, cooler water in the Basin during winter is also less stable because of the reduced amount of energy needed to mix the water column. Short term disturbances can mix the water column down to or below the level of the plume in any particular 24-hour period.

From early March until late May, the plume begins to strongly develop again. In March, the plume has increased up to 20 to 30 m in depth, although not always penetrating far into the reservoir. In April of the past three years, the plume has been present at a depth of 30 m to at least LV14. However, it is unstable, and at times represented by two or more short plumes extending 2 to 4 km into the Basin. Again shifts in weather patterns likely disrupt flow to the plume causing it to dissipate and reform. Ford (1990) described this in general for situations similar to those in Las Vegas Bay. Fischer and Smith (1983) described this occurrence in Las Vegas Bay during their 1980 investigations. By May, the thermocline has strengthened and stabilized, and is located at 9 to 15 m in depth depending on weather patterns. From this time, to sometime after December, the plume is tightly associated with the thermocline, and extends well

into the Basin. There are, however, occurrences during all months of the year when much of the flow begins at the Wash confluence as an overflow, with the plunge point occurring as far as 2 to 3 km into the lake due to the greater degree of stratification in the inner Bay.

In June through early September, the lake is strongly stratified, and the thermocline is located between 15 m (in June) and 30 m (in September). The plume remains intact on the bottom portion of the epilimnion, immediately above the thermocline. It is tightly constrained retaining its identity to at least LV12 or LV14. Occasionally we detected elevated conductance readings at the bottom of the epilimnion (about 30 m in depth) at Hoover Dam demonstrating that in late summer the plume may be very extensive.

Dissolved Oxygen Concentration

During the period of this study, patterns of dissolved oxygen demonstrated a predictable pattern. The lowest dissolved oxygen concentrations were measured in the hypolimnion of the inner portion of the Bay immediately downstream from the Las Vegas Wash confluence. As stratification intensified, concentrations in the hypolimnion continuously decreased. This expanded further into the main body of the Basin as summer progressed (Fig. 3a-f). Anoxic conditions existed below the thermocline from July into October. Development of this pattern is from the effects of organic load being introduced from Las Vegas Wash, and represents decomposition of material as it settles out of the plume. The further from the inflow area, the lighter the load and the higher the dissolved oxygen concentration.

Each summer, an unusually intense metalimnetic oxygen minima was found at sampling stations LV14 and Hoover Dam. Although a common occurrence in reservoirs, the intensity of the metalimnetic oxygen minima in Boulder Basin is likely from effects of material (nutrient

loading and increased biological production) brought into the main body of Boulder Basin from the Wash. Because the plume follows the thermocline, some of this depression results from biological decomposition processes associated with loading of organic material by the plume, and the increased standing crop of biological organisms. This is one of many remnants of the plume that extends well into the reservoir. Even after the plume has seemingly been dispersed as measured by its conductance signature, evidence for its influence takes other forms. For example, Burke (1977) reported that zooplankton respiration in the metalimnion accounts for a substantial portion of this reduction in dissolved oxygen in the metalimnion of Lake Mead. Zooplankton populations are substantially higher in the inner Bay (Personal Communication, Dr. John Beaver, Beaver Schaberg and Associates, Shaker Heights, Ohio) , and in the metalimnion (Baker et al. 1977).

Inflow-Outflow Patterns

Shifts in the pattern of inflow and outflow produce significant short and longterm changes in the water quality of Boulder Basin. Shortterm changes and effects are primarily due to infrequent flash flood events that occur in Las Vegas Wash or other arroyos. Although not studied within the context of this study, these could potentially produce large influxes of organic material, and have substantial shortterm effects on the extent and composition of the plume. We have yet to investigate the influence of above normal flows through the reservoir which occur during the infrequent years of high runoff in the Colorado River watershed.

There are two main outflows to Boulder Basin. The largest outflow is through Hoover Dam. Normal daily outflows cycle from a low of about 58 $m^3 \cdot sec^{-1}$ to peaks of 1420 $m^3 \cdot sec^{-1}$. The second outflow is through the intake to the Southern Nevada Water Authority (SNWA) with

a capacity of 1.5 x 10^6 $m^3 \cdot day^{-1}$ (Roefer et al. 1996). Both these sources remain relatively constant from year to year, and longterm changes are effected by shifts in inflow patterns to the reservoir.

Las Vegas Wash Inflow

Inflow patterns from Las Vegas Wash are predictable and have not changed over the last 20 years. However, volume has increased substantially, doubling in the past ten years. Fischer and Smith (1983) reported that the plume inner Bay was variable depending upon weather. Baker et al. (1977) reported the plume was located on the bottom during isothermal conditions, and in the metalimnion during summer stratification. We found this also to be the case even though both previous investigations were done when the volume of Wash inflow was half that of the present. While these other investigations reported that the position of the plume quickly changed in the water column, our studies found it to be quite predictable, except during late winter and early spring. The increased flow of the Wash likely forces the interflow to maintain a more stable position and to extend further into the Basin. Changes in the conductance and relationship of the density of the Wash inflow to that of the stratified Bay, works together to enforce the predictable nature of the plume.

The average flow into the Basin from the Wash 15 years ago was less than 3 $m^3 \cdot sec^{-1}$; it presently exceeds 6 $m^3 \cdot sec^{-1}$. As the population continues to increase, so will the inflow. Nevada receives return flow credits, and the more water returned to Lake Mead, the more can be removed through municipal intakes. The Wash collects nearly all the non-point source surface runoff from the watershed along with the treated effluent from three major sewage treatment facilities located between 10 and 18 km upstream. While inflow once meandered through a series of

natural wetlands which allowed for natural cooling and natural nutrient removal, it presently travels in an unimpeded channel from source to the lake due to head cutting which eroded the channel to its present configuration. Due to the reduced flow time from the treatment facilities, and to the fact that water is warmed during the tertiary treatment process, inflow from the Wash enters the lake at a temperature warmer than historically documented. This result tends to force the plume higher into the water column of the Bay. Mean temperature of the inflow has increased from about 21°C to 25 °C in the last five years (Roline and Sartoris 1996). The average specific conductance of this inflow at a flow of about 6 $m^3 \cdot sec^{-1}$ is about 2,400 $\mu S \cdot cm^{-1}$. The dilution of saline ground water by increased effluent input acts to reduce conductivity, thus, influencing the position of the plume in the water column. This tends to exacerbate the biological problems (e.g., eutrophication) of the inner Bay. Total dissolved solid load into the inner Bay, while not increasing in concentration, has increased by nearly 100 percent (1.72×10^8 vs. 3.08×10^8 $kg.yr^{-1}$) in the past decade because of higher volume input.

While Fischer and Smith (1983) reported that only 10 percent of the nutrients introduced by the Wash inflow were available for algal production in 1980, increased biological production (chlorophyll *a* concentration) in the past year indicates that this percentage may be increasing due to the changing hydrodynamics. Although nutrient inputs, such as total nitrogen, have remained relatively constant in the Wash inflow, the higher volume of inflow has resulted in less dilution. This in turn has resulted in the higher measured chlorophyll *a* concentrations.

Colorado River Inflow

The rate and volume of inflow from the Colorado River dictates how far downstream it directly influences the limnology of Lake Mead. Its influence on the limnology of Boulder Basin and Lake Mead as a whole can be identified by its lower conductivity signature. During the summer of 1995 and 1996, metalimnetic interflow existed from the Colorado River confluence to Hoover Dam (Fig. 7). We and others observed this interflow across the entire Boulder Basin, including the Saddle Island Intake to the Southern Nevada Water System (Personal Communication, Ms. Peggy Roefer, Southern Nevada Water System). This influence continued from June through September 1996. Inflows to Lake Mead from the Colorado River (releases from Glen Canyon Dam, about 400 km upstream) were greater than normal in early 1996. For seven days, from March 27 through April 3, 1996, controlled flooding of the Colorado River in the Grand Canyon resulted in the streamflow to Lake Mead to be continuously about 1250 $m^3 \cdot sec^{-1}$. This influenced the persistence and extent of this intrusion. This particular flow alone resulted in a nearly 1 m rise in surface elevation of Lake Mead. Flows the rest of the summer into Lake Mead were mostly below 550 $m^3 \cdot sec^{-1}$, or slightly below normal, but somewhat higher than in the previous few years. These data demonstrate that flows of the magnitude of those that occurred during the controlled flooding, if frequent in occurrence, will influence the limnology of Lake Mead well into the Boulder Basin. We also observed the Colorado River interflow in Boulder Basin during a similar time period in 1995, although not quite as prominent. Flows in 1993 and 1994 were lower, and the Colorado River interflow was not observed in Boulder Basin.

Management Significance

There is an abundance of literature documenting the existence of poor water quality due to the inflow from Las Vegas Wash (Bureau of Reclamation 1965 and 1967, FWPCA 1967 and 1970, PHS 1965, Blackman 1968, Hoffman et al. 1971, Sartoris and Hoffman 1971, Baker et al. 1977, EPA 1971a and 1971b, Univ. Ariz. 1971, Everett 1972, Deacon and Tew 1973, Staker et al. 1974, Deacon 1975, Egdorf 1976, Deacon 1976, Goldman et al. 1976, Tew et al. 1976, Deacon 1977, Baker et al. 1977, Goldman and Deacon 1978, URS 1979, Prentki et al. 1980, Baker and Paulson 1980, Brown and Caldwell 1982a and 1982b, Evans and Paulson 1983, Morris and Paulson 1983, Fischer and Smith 1983, Paulson 1986 and 1987). Investigations of currents in Boulder Basin of Lake Mead performed in 1967 indicated that "low-quality" water from Las Vegas Bay might enter the Southern Nevada Water System at Saddle Island (Sartoris and Hoffman 1971). Various studies of the Basin since that time continue to document the existence of poor water quality due to inflow from Las Vegas Wash. The most recent documentation of the effects of poor water quality include Goldstein et al. (1996), LaBounty and Horn (1996), Roefer et al. (1996), and Bevans et al. (1996).

Goldstein et al. (1996) documented 78 cases of cryptosporidiosis occurring in Las Vegas in early 1994. They concluded that the outbreak was linked to drinking water supply and that it began and ended very suddenly. Roefer et al. (1996) discussed the outbreak and pointed out that it is especially disturbing to the water treatment industry that even though the most stringent and reasonable engineering and technical controls are utilized, an outbreak like this can still occur. Finally, they stated that one of the important components of assessing the potential for an

outbreak is to examine the water quality and how it is affected by, among other things, the wastewater treatment plant effluent and storm water runoff from the watershed.

Intakes to the Southern Nevada Water System are located about 40 m below the surface at Saddle Island about 2 km south of LV14. Data collected from late 1993 and early 1994 indicate the plume to be especially strong and continuous throughout the period October 1993 through March 1994. For example, on March 24, 1994, the plume was noted to be at least 30 m thick between 30 and 60 m in depth at LV14. The plume was also detected as far away as Calville Bay (about 12 km from the Wash) at a depth between 25 and 70 m. Thus, although we have not directly obtained data from the vicinity of the intake, there is good reason to suspect that at least on some occasions (late November to late March) water from the plume has the potential to be entrained by the intakes to the Southern Nevada Water System. By late April 1994 the plume rose to a shallower depth, above the intake zone. In 1995, the plume was not as stable, extensive, nor continuous as in 1994. However, in spring 1996, the plume was exceptionally strong past LV14 (Fig. 5). There were 21 documented cases of cryptosporidiosis in Clark County through September 1996, all in the first two quarters (Clark County Health District 1996).

The fact that we documented exceptionally high nutrient concentrations, and that Goldstein et al. (1996) documented the case of the water supply being the source of a cryptosporidiosis outbreak, is only an indication of the reality that a myriad of other inorganic, organic, and biological contaminants entering Boulder Basin are carried by a predictably persistent interflow out into the Basin. Bevans et al. (1996) reported the presence in Las Vegas Bay of organochlorines (pesticides and industrial compounds) and semivolatile industrial

compounds in both semipermeable membrane sampling devices and bottom sediment samples. They found DDT metabolites in bottom sediment samples from all their Las Vegas Bay sampling sites. They also detected organochlorines (including DDT residues) in carp tissue samples from Las Vegas Bay along with an indication of endocrine disruption. Concentration of DDT residues in carp tissue samples from Las Vegas Wash and Bay exceeded some USEPA consumption limits for fish and they concluded that the source of organochlorines was Las Vegas Wash. Bevans et al. (1996) provided evidence for endocrine disruption in carp from Las Vegas Bay. Although, the pathology is distinguishable, the specific organic compound(s) responsible and their source(s) are unknown. Results of monitoring for bacteria and organic compounds done in mid-December 1996 revealed to be highest in the plume extending from the Las Vegas Wash confluence. All these indications point to the fact that the major source of drinking water for the Las Vegas Valley is at risk when considering the concept of Best Management Practices (BMP) for future supplies.

It seems wise to be constantly mindful of the limnological features and the hydrodynamics of the Basin, and to pay very close management attention to the Basin as being the source of supply. The investment, which should now be obvious, will become increasingly so as the population of this fast growing region increases, and all of the things that have been discussed in this paper are exacerbated. As Las Vegas again doubles in size, so will inflows into Las Vegas Wash. Further, as lake volume changes (i.e., during drought periods), the volume of Las Vegas Bay is substantially reduced and the interflow may be more prominent. Changes in reservoir levels may also elevate the plume further away from intake elevations, or move it closer.

Table 1.- Seasonal depth of the plume in Boulder Basin, Lake Mead, Nevada-Arizona, and distance it is extends from the confluence of Las Vegas Wash based on data collected from 1991 through 1996.

Month	Distance into Basin	Depth
January	6 to 8 km	40 to 60 m
February	6 to 8 km	40 to 60 m
March	> 8 km	15 to 40 m
April	> 5 km	15 to 35 m
May	< 5 km	10 to 15 m
June	16 km (Hoover Dam)	10 to 20 m (variable)
July	16 km (Hoover Dam)	15 to 30 m
August	8 km	15 to 35 m
September	8 km	15 to 35 m
October	8 km	15 to 40 m
November	8 km	40 to 50 m
December	8 km	40 to 55 m

Table 2. - Total Inorganic Nitrogen ($mg \cdot L^{-1}$) From Ammonia and Nitrate Collected During 1996 From Boulder Basin, Lake Mead,Nevada

Date	Surface	1 Meter	3 Meter	Plume (Depth)	Date	Surface	1 Meter	3 Meters	Plume (Depth)
		LVO1					LVO2		
02/22	1.8	1.7	9.6		01/18	0.9	0.9	0.9	5.5(14)
03/26	2.8	2.6	7.9		02/22	0.7	0.6	0.7	1.6(11)
04/23	5.5	5.8	6.3		03/26	1.3	1.3	1.3	4.2(9)
05/20	6.8	6.8	5.4		04/23	3.5	3.5	2.5	7.0(11)
06/13	3.1	3.2	8.1		05/20	2.5	2.5	2.6	5.3(11)
06/27	1.5	1.5	11.7		06/13	2.2	2.4	2.9	6.6(6)
07/16	2.6	2.7	6.4		06/27	1.7	1.4	1.6	2.8(11)
08/01	3.5	3.4	7.5		07/16	2.1	2.2	2.1	3.8(9)
08/14	3.3	3.1	11.1		08/01	2.3	2.3	2.4	7.1(8)
08/28	1.6	1.6	2.9		08/14	1.3	1.3	1.3	7.6(10)
09/25	1.6	1.6	11.0		08/28	1.6	1.5	1.6	5.5(13)
10/17	1.4	1.5	3.3		09/25	1.3	1.3	1.2	4.6(14)
11/19	12.2	12.7	13.9		10/17	1.3	1.3	1.3	3.2(12)
12/18	1.4	14.0	10.8		11/19	0.9	0.9	0.8	2.4(13)
					12/18	0.8	0.8	0.9	4.7(14)
		LV03					LV05		
01/18	0.9	0.8	0.9	3.5(18)	01/18	0.6	0.6	0.6	3.1(24)
02/22	0.6	0.6	0.6	1.7(19)	02/22	0.7	0.6	0.7	3.3(23)
03/26	0.7	0.7	0.6	1.6(17)	03/26	0.6	0.6	0.6	1.1(25)
04/23	2.6	2.7	1.5	5.5(15)	04/23	0.7	0.8	0.8	3.7(21)
05/20	1.3	1.4	1.4	5.1(11)	05/20	1.0	1.0	1.0	3.5(13)
06/13	3.0	3.1	3.1	5.2(11)	06/13	2.4	2.4	2.4	4.8(5)
06/27	1.4	1.4	1.6	4.1(13)	06/27	1.1	1.2	1.2	1.7(11)
07/16	2.0	2.0	2.0	5.5(12)	07/16	1.7	1.8	1.7	6.9(12)
08/01	1.7	1.7	1.6	8.0(11)	08/01	1.3	1.3	1.3	4.6(11)
08/14	1.5	1.4	0.7	7.7(10)	08/14	1.7	1.6	1.0	5.5(9)
08/28	1.4	1.3	1.3	5.8(13)	08/28	1.2	1.2	1.2	3.3(15)
09/25	1.1	1.1	1.0	3.1(18)	09/25	0.9	0.9	0.9	3.7(21)
10/17	1.2	1.1	1.1	3.1(19)	10/17	0.8	0.8	0.8	0.8(21)
11/19	0.7	0.7	0.7	1.9(19)	11/19	0.7	0.7	0.7	1.4(25)
12/18	0.7	0.8	0.7	2.8(19)	12/18	0.7	0.8	0.8	2.5(27)
		LVO8					LV10		
01/18	0.6	0.6	0.6	2.8(41)	03/26	0.6	0.6	0.6	1.5(51)
02/22	0.6	0.6	0.6	2.4(41)	04/23	0.5	0.5	0.5	0.9(24)
03/26	0.6	0.6	0.6	0.9(31)	05/20	0.8	0.7	0.9	1.1(27)
04/23	0.5	0.5	0.6	1.8(31)	06/13	1.2	1.2	1.2	1.2(9)
05/20	0.9	0.8	0.8	1.7(11)	07/16	0.7	0.7	0.7	1.1(5)
06/13	1.6	1.6	1.6	1.8(5)	08/01	0.8	0.8	0.8	1.6(13)
06/27	1.0	1.0	1.0	1.4(13)	08/14	0.7	0.7	0.7	1.1(17)
07/16	0.9	0.9	0.9	2.2(12)	08/28	0.5	0.5	0.5	1.2(15)
08/01	0.9	0.9	0.9		09/25	0.4	0.4	0.4	1.1(13)
08/14	0.9	0.9	0.7	1.7(15)	10/17	0.6	0.6	0.6	0.9(21)
08/28	0.7	0.7	0.7	1.5(13)	11/19	0.6	0.6	0.6	0.8(45)
09/25	0.5	0.5	0.5	0.9(21)	12/18	0.6	0.7	0.6	1.2(41)
10/17	0.7	0.7	0.7	0.5(39)					
11/19	0.6	0.5	0.6	1.2(40)					
12/18	0.6	0.7	0.7	2.4(41)					

Table 2. - Total Inorganic Nitrogen ($mg \cdot L^{-1}$) From Ammonia and Nitrate Collected During 1996 From Boulder Basin, Lake Mead,Nevada

Date	Surface	1 Meter	3 Meter	Plume (Depth)	Date	Surface	1 Meter	3 Meters	Plume (Depth)
		LV12					LV14		
06/27	0.6				01/18	0.5	0.5	0.5	
07/16	0.7	0.6	0.6	1.2(13)	02/22	0.5	0.5	0.5	0.5(50)
08/01	0.7	0.7	0.7	1.1(17)	03/26	0.5	0.5	0.5	0.7(33)
08/14	0.6	0.5	0.5	1.1(15)	04/23	0.5	0.5	0.5	0.7(27)
08/28	0.5	0.5	0.5	0.8(15)	05/20	0.6	0.4	0.4	0.5(13)
09/25	0.4	0.4	0.5	0.8(21)	06/13	0.5	0.5	0.4	
10/17	0.5	0.6	0.6		06/27	0.5	0.5	0.5	
11/19	0.6	0.5	0.6	0.9(47)	07/16	0.4	0.5	0.5	0.7(50)
12/18	0.5	0.5	0.7	1.1(68)	08/01	0.4	0.4	0.3	
					08/14	0.4	0.3	0.3	0.4(20)
					08/28	0.3	0.5	0.5	0.5(20)
					09/25	0.5	0.5	0.6	0.4(19)
					10/17	0.5			
					11/19	0.6	0.6	0.6	0.8(45)
					12/18	0.5	0.6	0.5	0.7(68)

Literature Cited

APHA. 1992. Standard Methods for the Examination of Water and Wastewater. 18th edition. Amer. Public Health Assoc. Washington, D.C.

Baker, J. R. , J. E. Deacon, T. A. Burke, S. S. Egdorf, L. J. Paulson, and R. W. Tew. 1977. Limnological Aspects of Lake Mead, Arizona-Nevada. U.S. Bureau of Reclamation Report No. REC-ERC-77-9, Engineering and Research Center, Denver, Colorado. 83 p.

Baker, J. R. and L. J. Paulson. 1980. Influence of the Las Vegas Wash density current on nutrient distribution and phytoplankton growth in Las Vegas Bay, Lake Mead. P. 1638-1646 *In:* H.G. Stefan (ed.), Symposium on Surface Water Impoundments. Amer. Soc.of Civil Engineers, Minneapolis, Minnesota, June 2-5.

Bevans, H. E., S. L. Goodbred, J. F. Meisner, S. A. Watkins, T. S. Gross, N. D. Denslow and T. Schoeb. 1996. Synthetic organic compounds and carp endochrinology and histology in Las Vegas Wash and Las Vegas and Callville Bays of Lake Mead, Nevada, 1992 and 1995. U.S. Geolog. Surv. Water Resources Invest. Rep. 96-4266. 12 p.

Blackman, W. C., Jr., 1968. Pollution of Las Vegas Wash and Lake Mead and recommendations for necessary studies. Memorandum to Director, SW Region, Federal Water Pollution Control Administration and Project Director, Colorado River Basin Water Quality Control Program. February 23, 1968. 16 p., plus appendices of raw data.

Brown and Caldwell and Culp/Wesner/Culp. 1982a. Appendices A, B, and C for Las Vegas Valley Water Quality Program, Water Quality Standards Study Report. Report submitted to the Las Vegas Valley Water Quality Study Board. March 8, 1982.

Brown and Caldwell and Culp/Wesner/Culp. 1982b. Appendices D, E, and F for Las Vegas Valley Water Quality Program, Water Quality Standards Study Report. Report submitted to the Las Vegas Valley Water Quality Study Board. March 8, 1982.

Bureau of Reclamation, U.S. Department of Interior . 1941. Lake Mead density currents investigations 1937-40. Vol 1 and 2. 453 p.

Bureau of Reclamation, U.S. Department of Interior . 1947. Lake Mead Density Currents Investigations. 1941-46, Vol 3. p. 454-904.

Bureau of Reclamation, U.S. Department of Interior . 1965. Water Chemistry Survey of Boulder Basin Lake Mead. Chemical Engineering Branch, Division of Research, Report No. ChE-46, Denver, Colorado. 36 p.

Bureau of Reclamation, U.S. Department of Interior. 1967. Water Quality Study of Lake Mead. Chemical Engineering Branch, Division of Research, Report No. ChE-70, Denver, Colorado. 155 p.

Burke, T. A. 1977. The Limnetic Zooplankton Community of Boulder Basin, Lake Mead in Relation to the Metalimnetic Oxygen Minimum. M.S. Thesis, Univ. of Nevada, Las Vegas. 95 p.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol.and Oceanogr. 22:361-369 Clark County Health District. 1996.

Deacon, J. E. and R. W. Tew. 1973. Interrelationships between chemical, physical, and biological conditions of the waters of Las Vegas Bay of Lake Mead. Dept. of Biolog. Sci., Univ. of Nevada, Las Vegas. Final Report to Las Vegas Valley Water District. 186 p.

Deacon, J. E. 1975. Lake Mead monitoring program. Dept. of Biolog. Sci., Univ. of Nevada, Las Vegas. Final Report to Clark County Wastewater Management Agency. 207 p.

Deacon, J. E. 1976. Lake Mead monitoring program. Dept. of Biolog. Sci., Univ. of Nevada, Las Vegas. Final Report to Clark County Sanitation District No. 1, Wastewater Treatment Physical Development Section. 182 p.

Deacon, J. E. 1977. Lake Mead monitoring program. Dept. of Biolog. Sci., Univ. of Nevada, Las Vegas. Final Report to Clark County Sanitation District No. 1, Wastewater Treatment Physical Development Section. 55 p.

Egdorf, S. S. 1976. The nature and distribution of enteric bacteria in Las Vegas Bay. M.S. Thesis, Dept. of Biolog. Sci., Univ. of Nevada, Las Vegas. 84 p.

Evans, T. D. and L. J. Paulson. 1983. The influence of Lake Powell on the suspended sediment-phosphorus dynamics of the Colorado River inflow to Lake Mead. P. 57-70. *In*: V.D. Adams and V.A. Lamarra (eds). Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada. Ann Arbor Sci. Publ., November 16-19, 1981.

Everett, L. G. 1972. A mathematical model of primary productivity and limnological patterns in Lake Mead. Technical Report No. 13, Univ.of Arizona, Tucson, Arizona. 151 p.

Federal Water Pollution Control Administration, U.S. Department of Interior. 1967. Report on Pollution in Las Vegas Wash and Las Vegas Bay. Division of Technical Services, Cincinnati, Ohio and Colorado River Basin Water Quality Control Project, Denver, Colorado. 18 p., plus appendix with raw data.

Federal Water Quality Administration, U.S. Department of Interior. 1970. Analysis of Water Quality and Proposed Water Quality Standards for Lake Mead and the Lower Colorado River. Pacific Southwest Region, San Francisco, California. October 1970. 63 p.

Fischer, H. B. and R. D. Smith. 1983. Observations of transport to surface waters from a plunging inflow to Lake Mead. Limnol. Oceanogr. 28(2):258-272.

Ford, D. E. 1990. Reservoir transport processes. P. 15-42. *In*. K. W. Thornton, B. L. Kimmel and F.E. Payne (eds). Reservoir Limnology: Ecological Perspectives. John Wiley and Sons, New York.

Goldman, C. R., A. D. Jassby, L. J. Paulson, B. L. Kimmel and J. T. Rybock. 1976. A review of the limnology and water quality standards for Lake Mead. Ecol. Res. Assoc., Davis, California. Final Report to Clark County Sanitation Dist . No. 101 p.

Goldman, C. R. and J. E. Deacon. 1978. Recommended water quality standards for Las Vegas Bay and Las Vegas Wash. Special report prepared for City of Las Vegas and submitted to the Nevada Environmental Commission on August 10, 1978. 42 p.

Goldstein, S. T., D. D. Juranek, O. Ravenholt, A. W. Hightower, D. G. Martin, J. L. Mesnik, S. D. Griffiths, A. J. Bryant, R. R. Reich and B. L. Herwaldt. 1996. Cryptospoiridiosis: An outbreak associated with drinking water despite state-of-the-art water treatment. Ann Intern Med 124:459-468.

Healthwatch, Clark County (Nevada) Health Distric, Las Vegas, Nevada, 5(4):4 p.

Hoffman, D. A., P. R. Tramutt, and F. C. Heller. 1971. The effects of Las Vegas Wash effluent upon the water quality in Lake Mead. U.S. Bur. of Reclama., Report No. REC-REC-71-11, Denver, Colorado. 26 p.

Horne, A .J. and C. R. Goldman. 1994. Limnology. McGraw-Hill, Inc. New York. 576 p.

Kimmel, B. L., O. T. Lind and L .J. Paulson. 1990. Reservoir Primary Production. P. 133-194 *In* K. W. Thornton, B. L. Kimmel and F. E. Payne (eds). Reservoir Limnology: Ecological Perspectives. John Wiley and Sons, New York.

LaBounty, J. F. and M. Horn. 1996. Report of Significant Findings-Las Vegas Bay/Boulder Basin investigations. Bur. Reclam. Tech. Mem. No. 8220-96-14. 5 p.

Lara, J. M. and J. I. Sanders. 1970. The 1963-64 Lake Mead survey. Bur. of Reclam. Report. 172 p.

Morris, F. A. and L. J. Paulson. 1983. Current water quality trends in the Las Vegas Wash Wetlands. P. 125-138. *In*: V. D. Adams and V. A. Lamarra (eds). Symposium on the Aquatic Resources Management of the Colorado River Ecosystem, Las Vegas, Nevada. Ann Arbor Science Publ., November 16-19, 1981.

Paulson, L. J. 1986. Limnological monitoring data for Lake Mead during 1985. Lake Mead Limnol. Res. Ctr, Tech. Rept. No. 14, Univ. of Nevada, Las Vegas, 9 p., plus appendices with raw data.

Paulson, L. J. 1987. Limnological monitoring data for Lake Mead during 1986. Lake Mead Limnol. Res. Ctr, Tech. Rept. No. 16, Univ. of Nevada, Las Vegas. 8 p., plus appendices with raw data.

Paulson, L. J. and J. R. Baker. 1981. Nutrient interactions among reservoirs on the Colorado River. P. 1647-1658. *In* H.G. Stefan (ed). Proceedings of the Symposium on Surface water Impoundments. Amer. Soc. Civil Engr., New York.

Prentki, R. T., L .J. Paulson and J. R. Baker. 1980. Chemical and biological structure of Lake Mead sediments. Lake Mead Limnol. Res. Ctr., Tech. Rept. No. 6, Univ. of Nevada, Las Vegas. 89 p.

Prentki, R. T. and L. J. Paulson. 1983. Historical patterns of phytoplankton productivity in Lake Mead. P. 105-123. *In* V. D. Adams and V. A. Lamarra (eds). Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Science, Ann Arbor, Mich.

Public Health Service, U.S. Department of Health, Education, and Welfare. 1965. Algal and nutrient survey of the surface waters of Lake Mead, June 4-8, 1965. Division of Water Supply and Pollution Control, Technical Services Branch, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. 8 p.

Roefer, P. A., J .T. Monscvitz and D.J. Rexing. 1996. The Las Vegas cryptosporidiosis outbreak. Journ. Amer. Water Works Assoc. 88(9):95-106.

Roline, R. A. and J. J. Sartoris. 1996. Las Vegas wash water quality monitoring program 1995 report of findings. Tech. Mem. No. 8220-96-13. Bur. Reclam. Tech. Svc. Ctr. 11 p.

Sartoris, J. J. and D. A. Hoffman. 1971. Measurement of currents in Lake Mead with the deep water isotopic current analyzed (DWICA). Bur. of Reclam. Rep. REC-ERC-71-38. 17 p.

Staker, R. D., R. W. Hoshaw and L. G. Everett. 1974. Phytoplankton distribution and water quality indices for Lake Mead (Colorado River). J. of Phycology. 10:323-331.

Tew, R. W. , S. S. Egdorf and J. E. Deacon. 1976. Distribution of stream pollution in lake water. J. of Wat. Pollution Control Federation. 48:867-871.

Thornton, K. W. 1990. Perspectives on reservoir limnology. P.1-14. *In* K. W. Thornton, B. L. Kimmel and F. E. Payne (eds). Reservoir Limnology: Ecological Perspectives. John Wiley and Sons, New York.

URS Company. 1979. Water qality problems in Las Vegas Bay and Boulder Basin of Lake Mead. Clark County 208 Water Quality Management Plan, Clark County, Nevada. 244 p.

University of Arizona. 1971. Micronutrient and biological pattems in Lake Mead. Dept. of Hydrol. and Wat. Res., College of Earth Sci. and Dept. of Biolog. Sci. Final Report to U.S. Bur. of Reclam. 24 p., plus appendices of graphed data.

U.S. Environmental Protection Agency. 1971a. Report on Water Pollution Problems in Las Vegas Wash and Las Vegas Bay. Region IX, San Francisco, California. November 1971. 20 p.

U.S. Environmental Protection Agency. 1971b. Report on Pollution Affecting Las Vegas Wash, Lake Mead & the Lower Colorado River, Nevada-Arizona-California. Division of Field Investigations, Denver, Colorado and Region IX, San Francisco, California. December 1971. 52 p., plus appendices of water quality standards.

Vollenweider, R.A. 1970. Scientific fundamentals of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Rep. DAS/CSL/6827, Org. Econ. Coop. And Dev., Paris, 192p.

Figures

Tables

Table 1.- Seasonal depth of the plume in Boulder Basin, Lake Mead, Nevada-Arizona, and distance it extends from the confluence of Las Vegas Wash based on data collected from 1991 through 1996.

Table 2-Total inorganic nitrogen ($mg \cdot L^{-1}$) from ammonia plus nitrate collected during 1996 from Boulder Basin, Lake Mead, Nevada.

Figure 1.- Map of Lake Mead, a reservoir on the mainstem of the Colorado River, Nevada-Arizona.

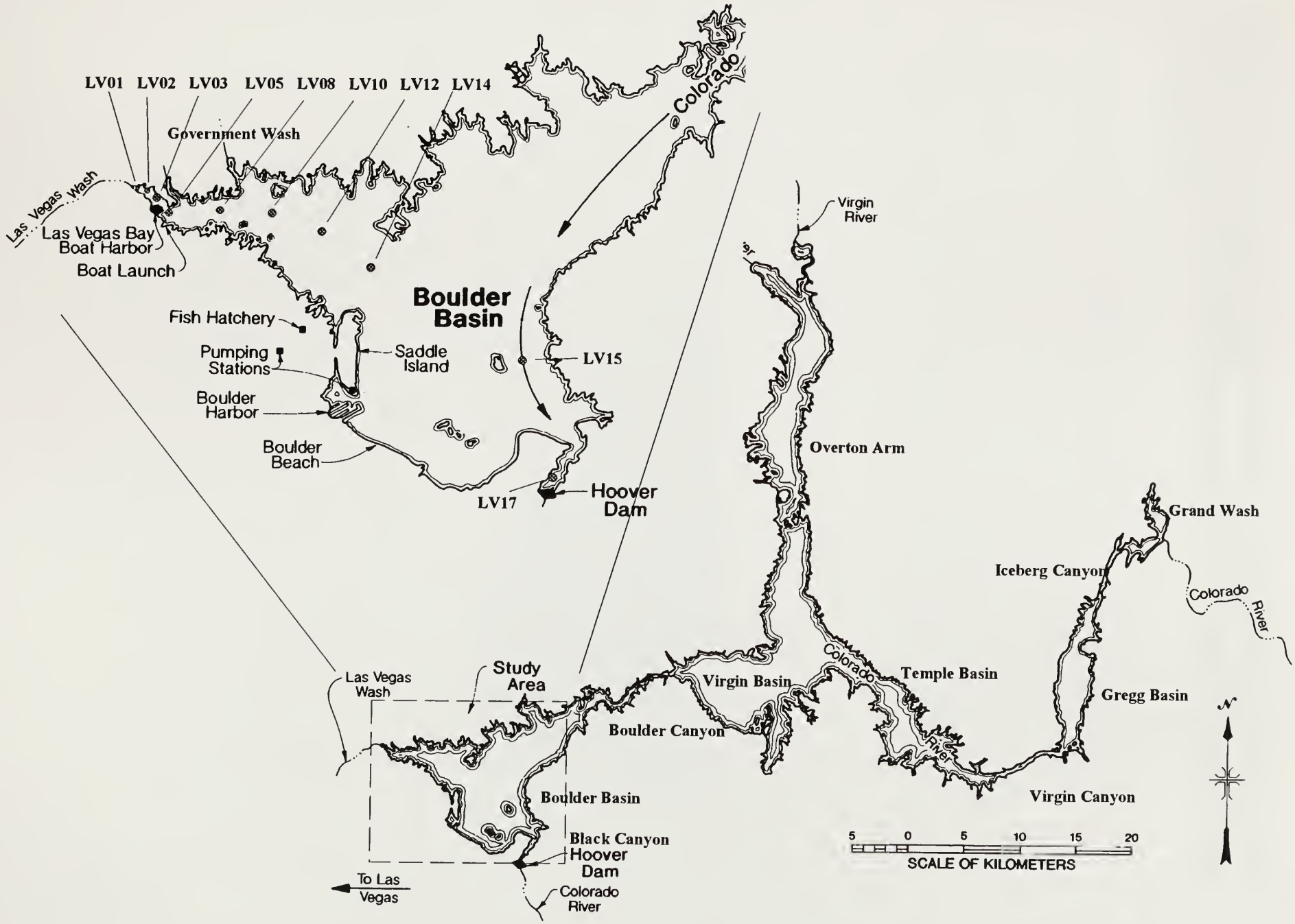

LV01
LV02
LV03
LV05
LV08
LV10
LV12
LV14
Government Wash
Las Vegas Wash
Las Vegas Bay
Boat Harbor
Boat Launch
Colorado
Boulder Basin
Fish Hatchery
Pumping Stations
Saddle Island
LV15
Boulder Harbor
Boulder Beach
LV17
Hoover Dam
Virgin River
Overton Arm
Grand Wash
Iceberg Canyon
Colorado River
Temple Basin
Gregg Basin
Virgin Basin
Boulder Canyon
Virgin Canyon
Las Vegas Wash
Study Area
Boulder Basin
Black Canyon
Hoover Dam
Colorado River
To Las Vegas
5 0 5 10 15 20
SCALE OF KILOMETERS
N

Figure 2.-Isopleth description of specific conductance and turbidity based upon data collected in the 16 km stretch for Boulder Basin from the confluence with Las Vegas Wash and Hoover Dam on March 26, 1996.

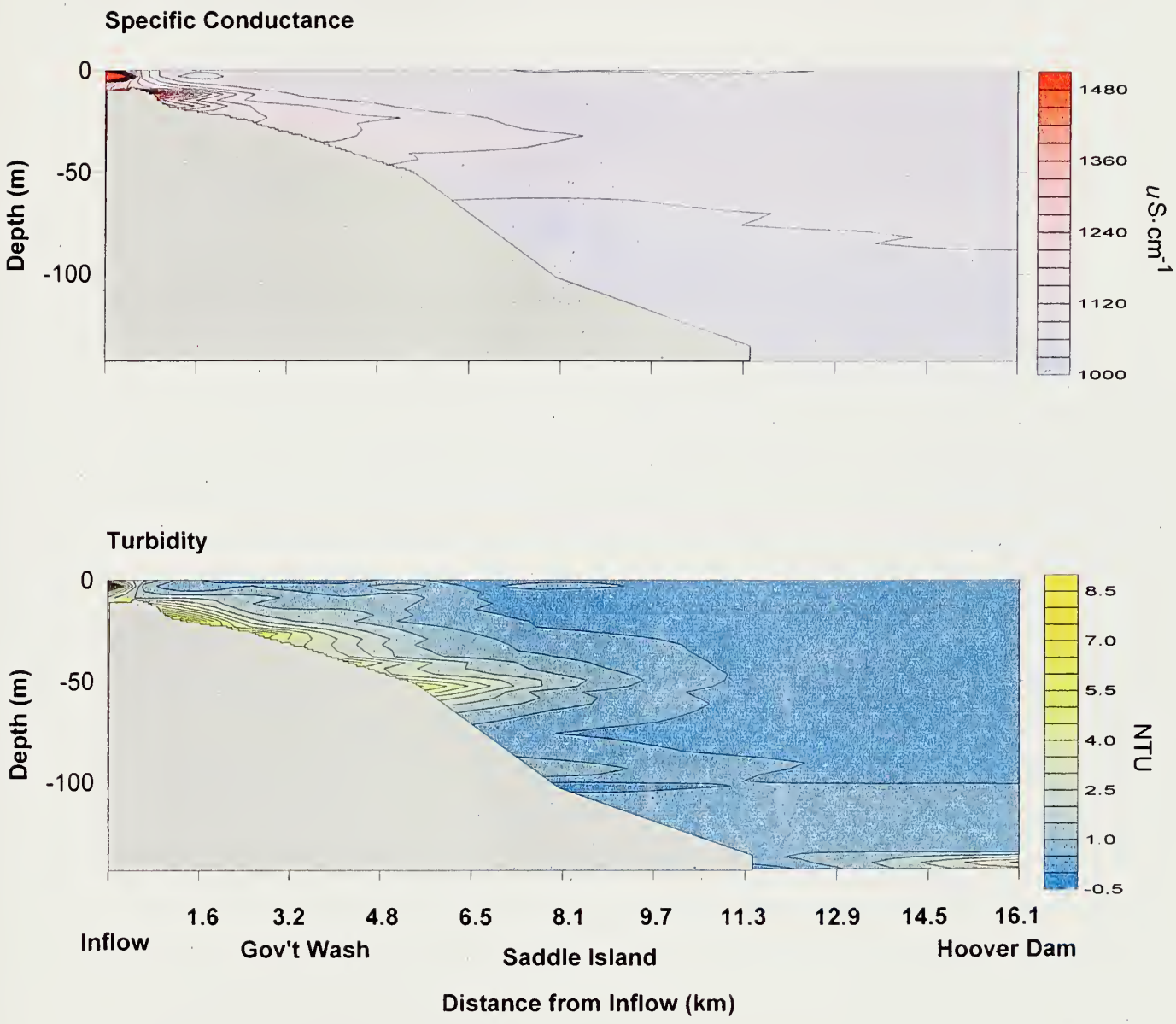

Specific Conductance
Depth (m)
0
-50
-100
1480
1360
1240
1120
1000
uS·cm-1
Turbidity
Depth (m)
0
-50
-100
8.5
7.0
5.5
4.0
2.5
1.0
-0.5
NTU
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Inflow
Gov't Wash
Saddle Island
Hoover Dam
Distance from Inflow (km)

Figure 3.-Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH values based upon data collected in the 16 km stretch of Boulder Basin from the confluence with Las Vegas Wash to Hoover Dam.

a. January 18, 1996

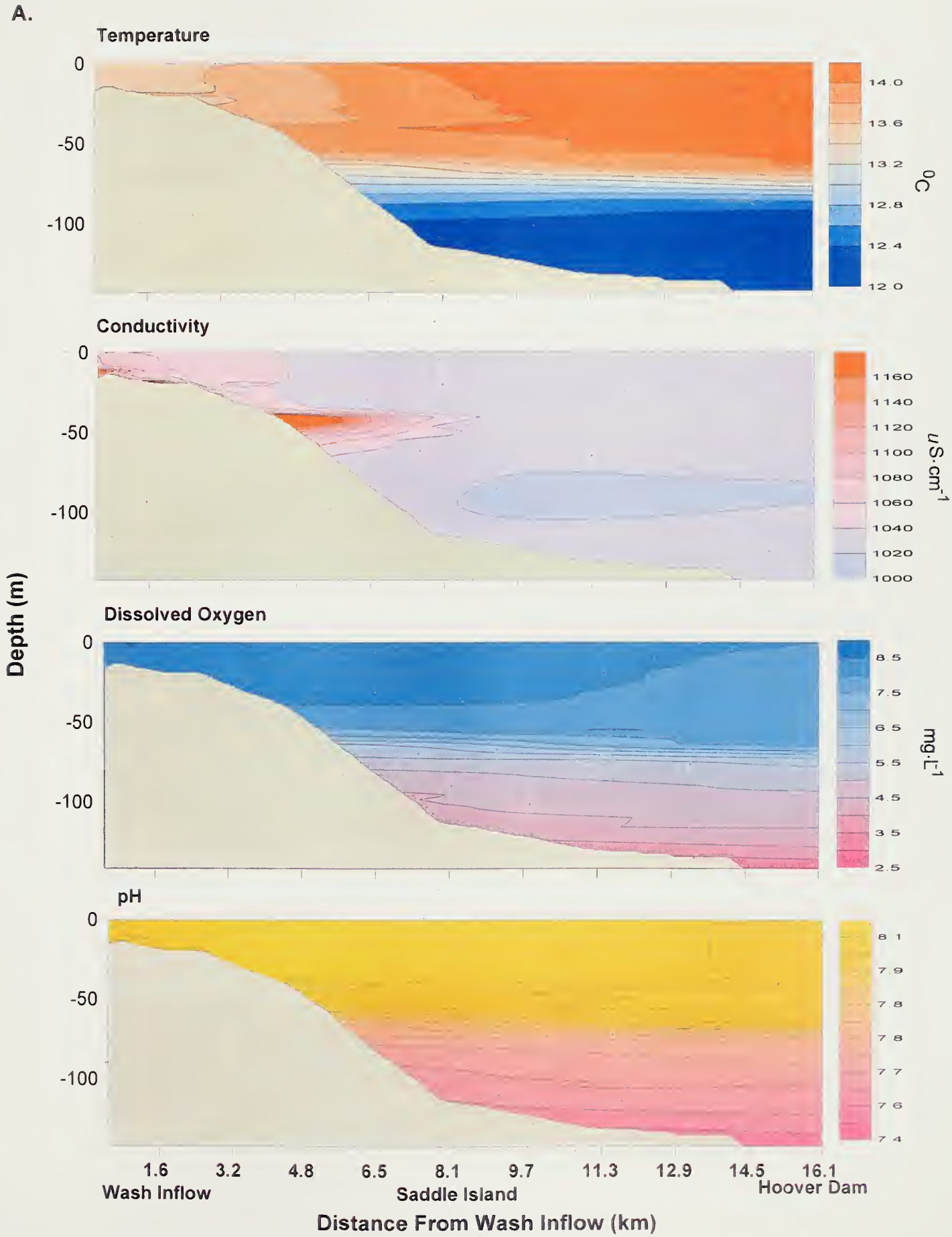

A.
Temperature
0
-50
-100
14.0
13.6
13.2
12.8
12.4
12.0
°C
Conductivity
0
-50
-100
1160
1140
1120
1100
1080
1060
1040
1020
1000
uS·cm-1
Dissolved Oxygen
0
-50
-100
8.5
7.5
6.5
5.5
4.5
3.5
2.5
mg·L-1
pH
0
-50
-100
8.1
7.9
7.8
7.8
7.7
7.6
7.4
Depth (m)
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Wash Inflow
Saddle Island
Hoover Dam
Distance From Wash Inflow (km)

Figure 3.-Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH values based upon data collected in the 16 km stretch of Boulder Basin from the confluence with Las Vegas Wash to Hoover Dam.

b. April 23, 1996

B.

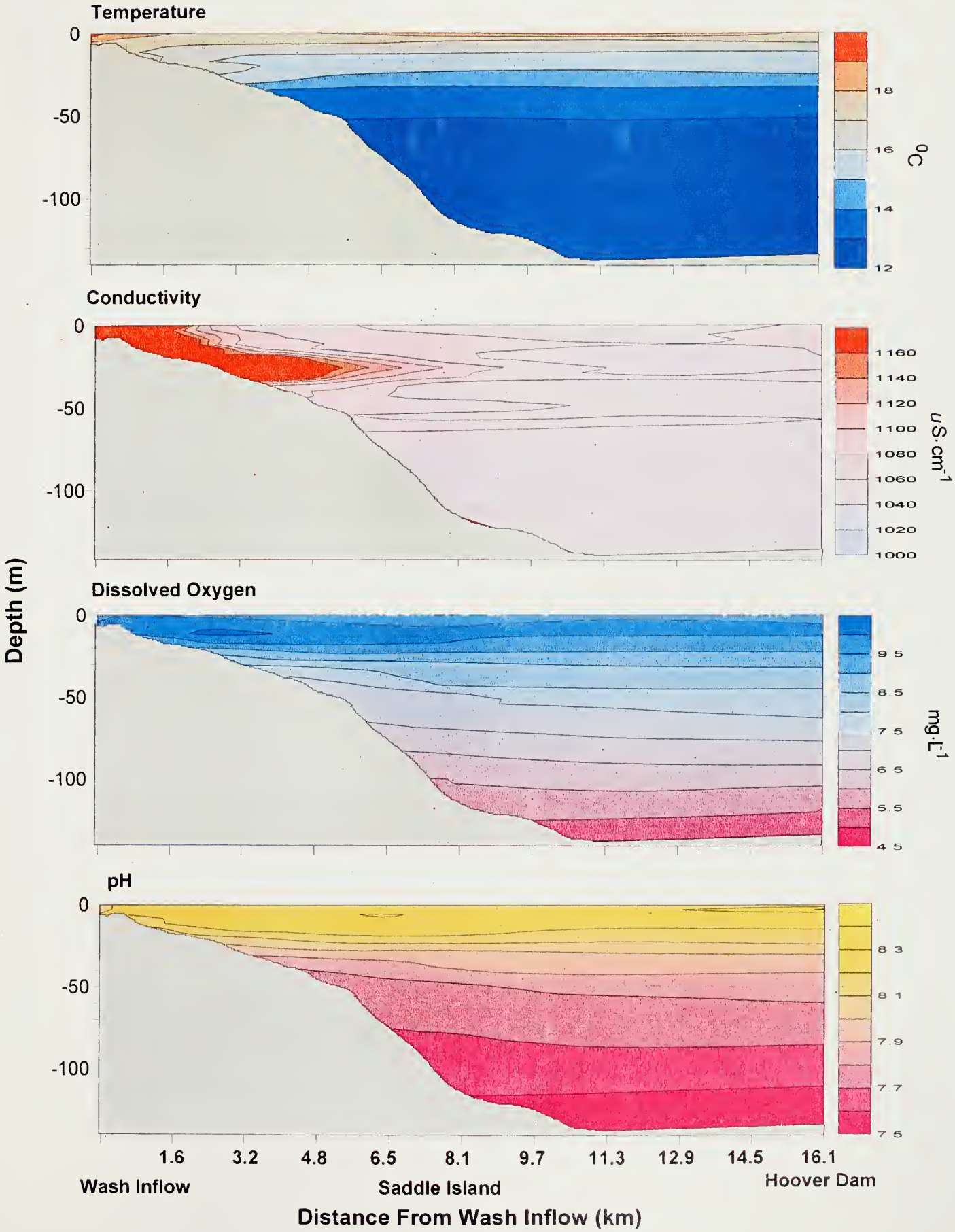

Temperature
0
-50
-100
18
16
14
12
°C
Conductivity
0
-50
-100
1160
1140
1120
1100
1080
1060
1040
1020
1000
uS·cm-1
Dissolved Oxygen
0
-50
-100
9.5
8.5
7.5
6.5
5.5
4.5
mg·L-1
pH
0
-50
-100
8.3
8.1
7.9
7.7
7.5
Depth (m)
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Wash Inflow
Saddle Island
Hoover Dam
Distance From Wash Inflow (km)

Figure 3.-Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH values based upon data collected in the 16 km stretch of Boulder Basin from the confluence with Las Vegas Wash to Hoover Dam.

c. June 13, 1996

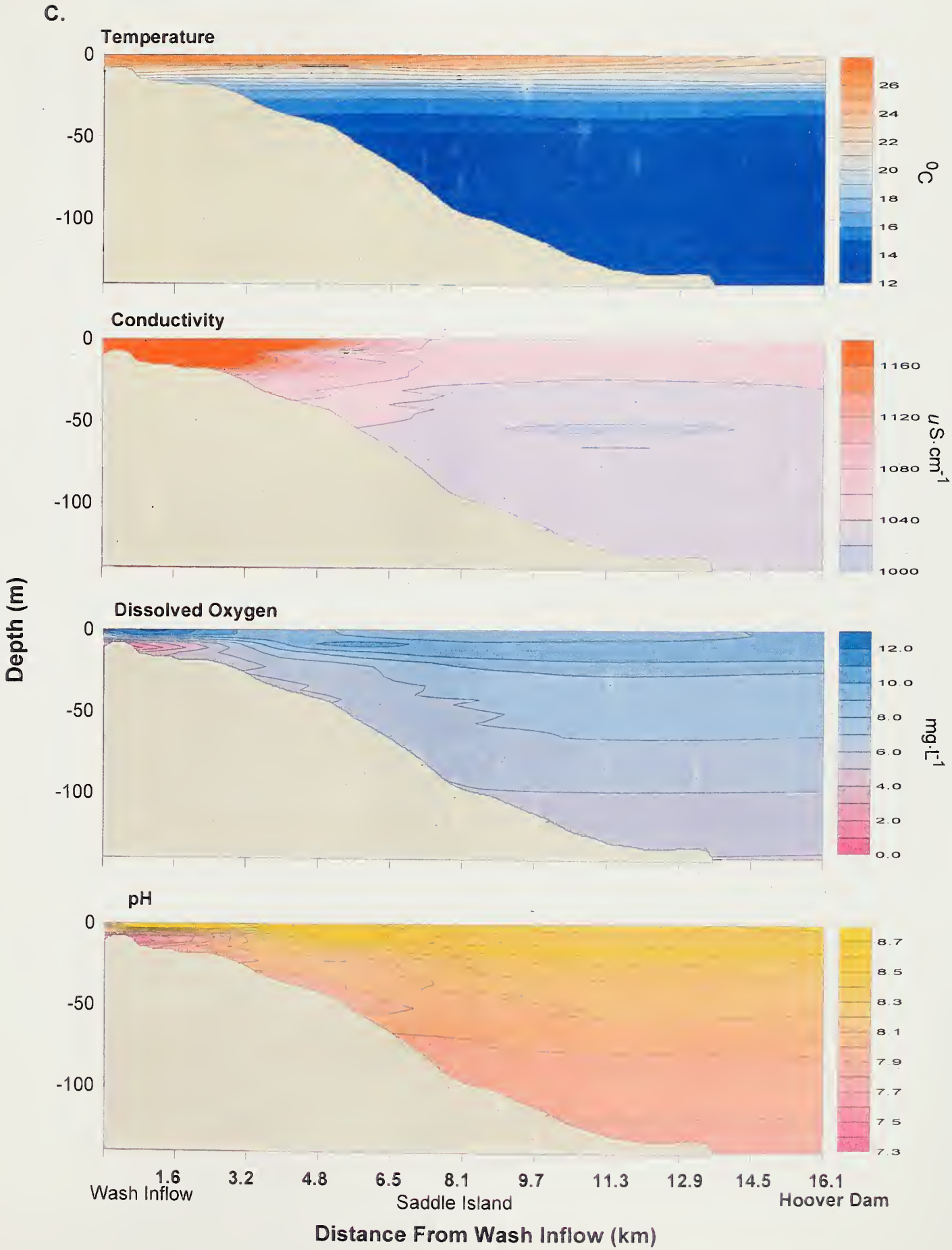

C.
Temperature
0
-50
-100
26
24
22
20
18
16
14
12
°C
Conductivity
1160
1120
1080
1040
1000
uS·cm-1
Dissolved Oxygen
12.0
10.0
8.0
6.0
4.0
2.0
0.0
mg·L-1
pH
8.7
8.5
8.3
8.1
7.9
7.7
7.5
7.3
Depth (m)
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Wash Inflow
Saddle Island
Hoover Dam
Distance From Wash Inflow (km)

Figure 3.-Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH
values based upon data collected in the 16 km stretch of Boulder Basin from the confluence with Las Vegas Wash to Hoover Dam.

d. August 28, 1996

D.

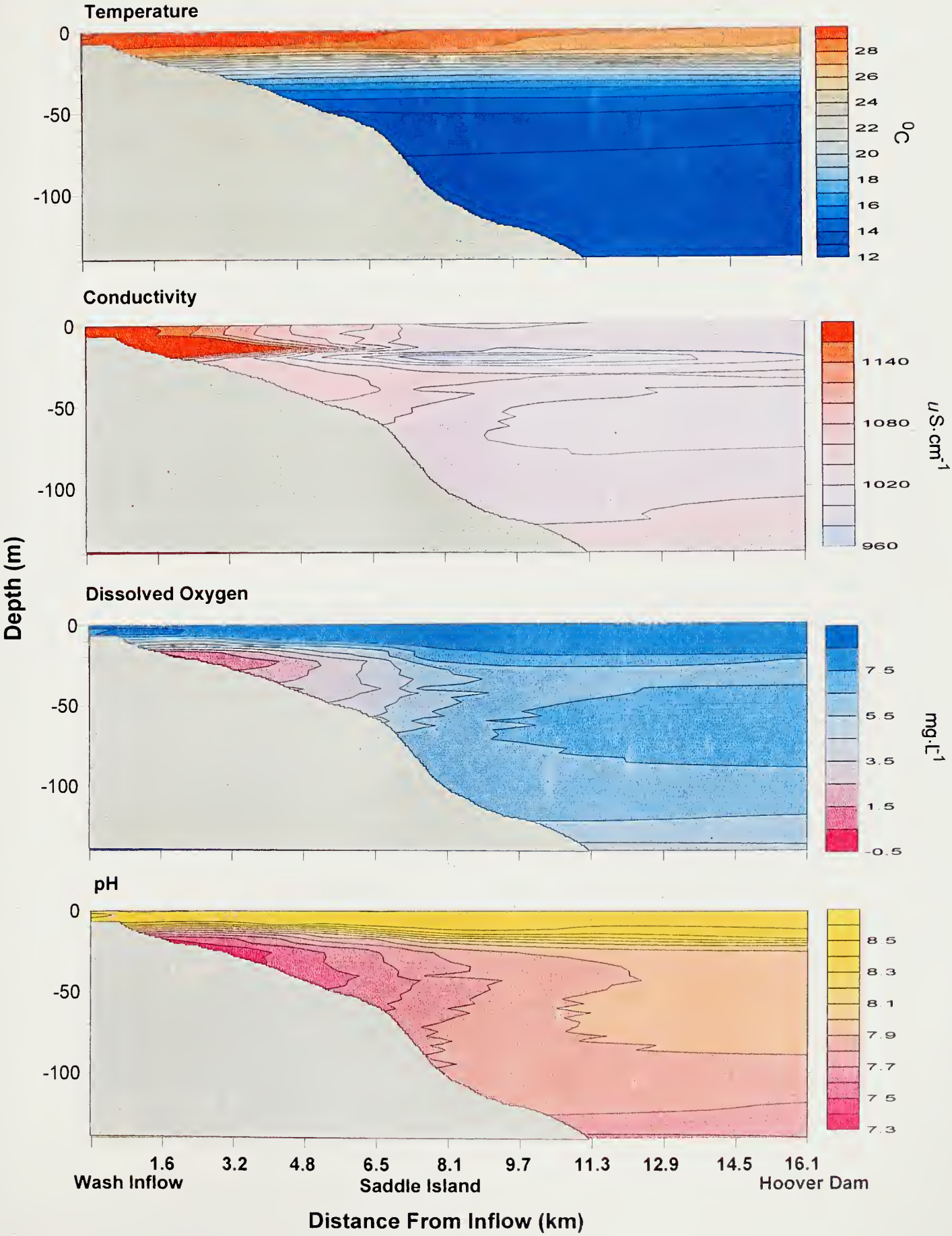

Temperature
0
-50
-100
28
26
24
22
20
18
16
14
12
°C
Conductivity
0
-50
-100
1140
1080
1020
960
uS·cm-1
Dissolved Oxygen
0
-50
-100
7.5
5.5
3.5
1.5
-0.5
mg·L-1
pH
0
-50
-100
8.5
8.3
8.1
7.9
7.7
7.5
7.3
Depth (m)
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Wash Inflow
Saddle Island
Hoover Dam
Distance From Inflow (km)

Figure 3.-Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH values based upon data collected in the 16 km stretch of Boulder Basin from the confluence with Las Vegas Wash to Hoover Dam.

e. September 25, 1996

E.

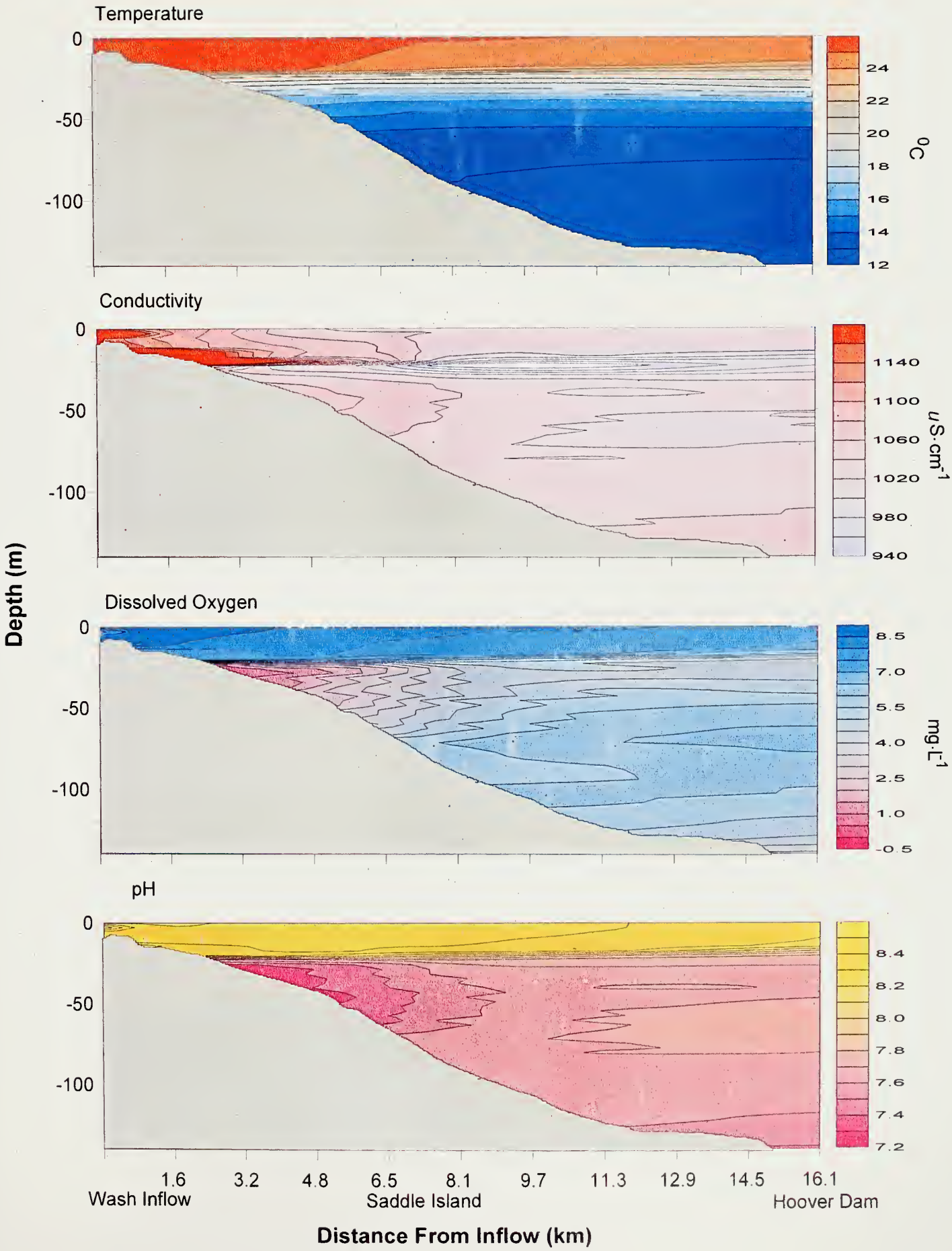

Temperature
0
-50
-100
24
22
20
18
16
14
12
°C
Conductivity
0
-50
-100
1140
1100
1060
1020
980
940
uS·cm-1
Dissolved Oxygen
0
-50
-100
8.5
7.0
5.5
4.0
2.5
1.0
-0.5
mg·L-1
pH
0
-50
-100
8.4
8.2
8.0
7.8
7.6
7.4
7.2
Depth (m)
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Wash Inflow
Saddle Island
Hoover Dam
Distance From Inflow (km)

Figure 3.-Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH values based upon data collected in the 16 km stretch of Boulder Basin from the confluence with Las Vegas Wash to Hoover Dam.

f. November 19, 1996

F.

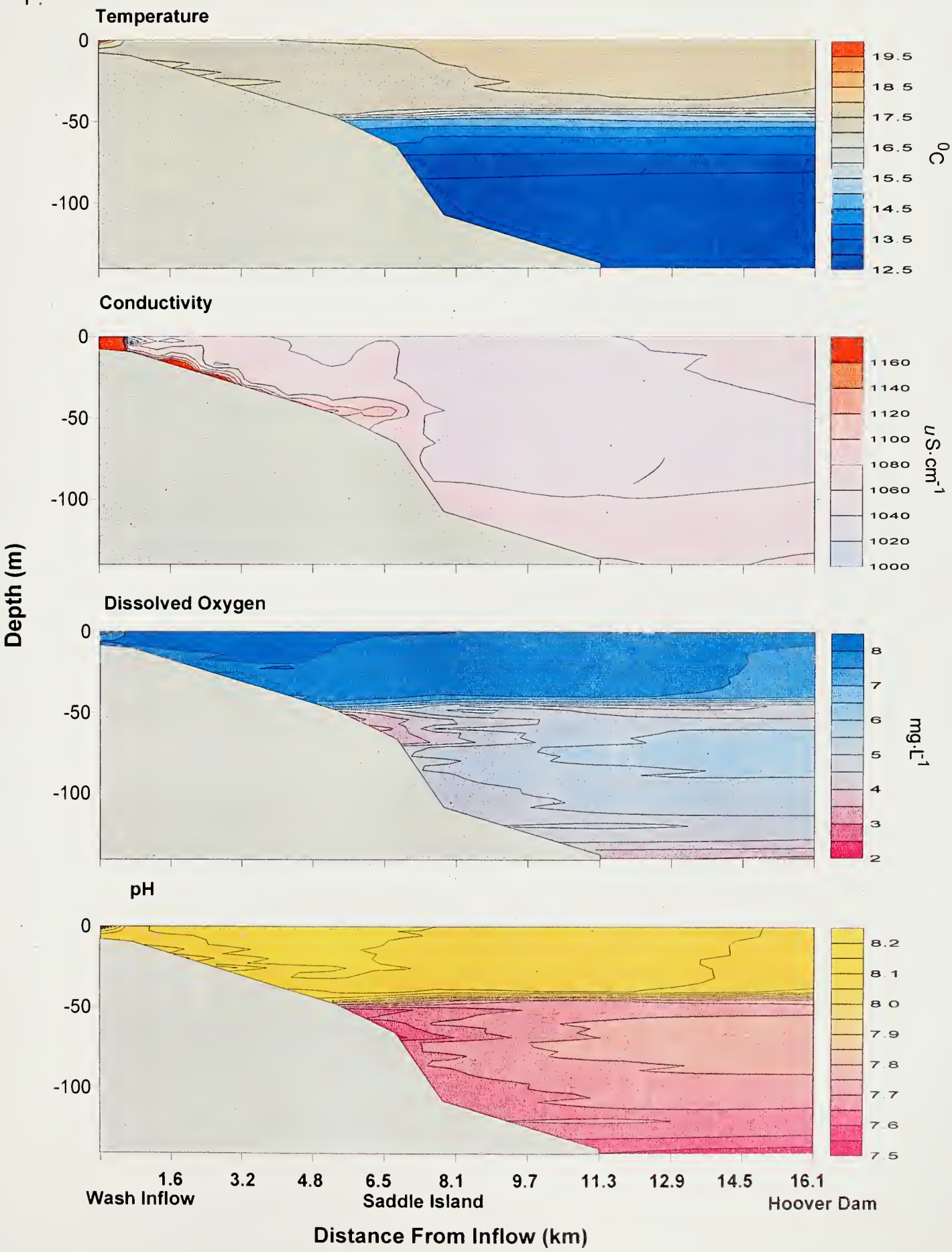

Temperature
0
-50
-100
19.5
18.5
17.5
16.5
15.5
14.5
13.5
12.5
°C
Conductivity
0
-50
-100
1160
1140
1120
1100
1080
1060
1040
1020
1000
uS·cm-1
Dissolved Oxygen
0
-50
-100
8
7
6
5
4
3
2
mg·L-1
pH
0
-50
-100
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
Depth (m)
1.6
3.2
4.8
6.5
8.1
9.7
11.3
12.9
14.5
16.1
Wash Inflow
Saddle Island
Hoover Dam
Distance From Inflow (km)

Figure 4.-Time series isopleth data collected at LV14 (Las Vegas Bay) from August 1993 through November 1996.

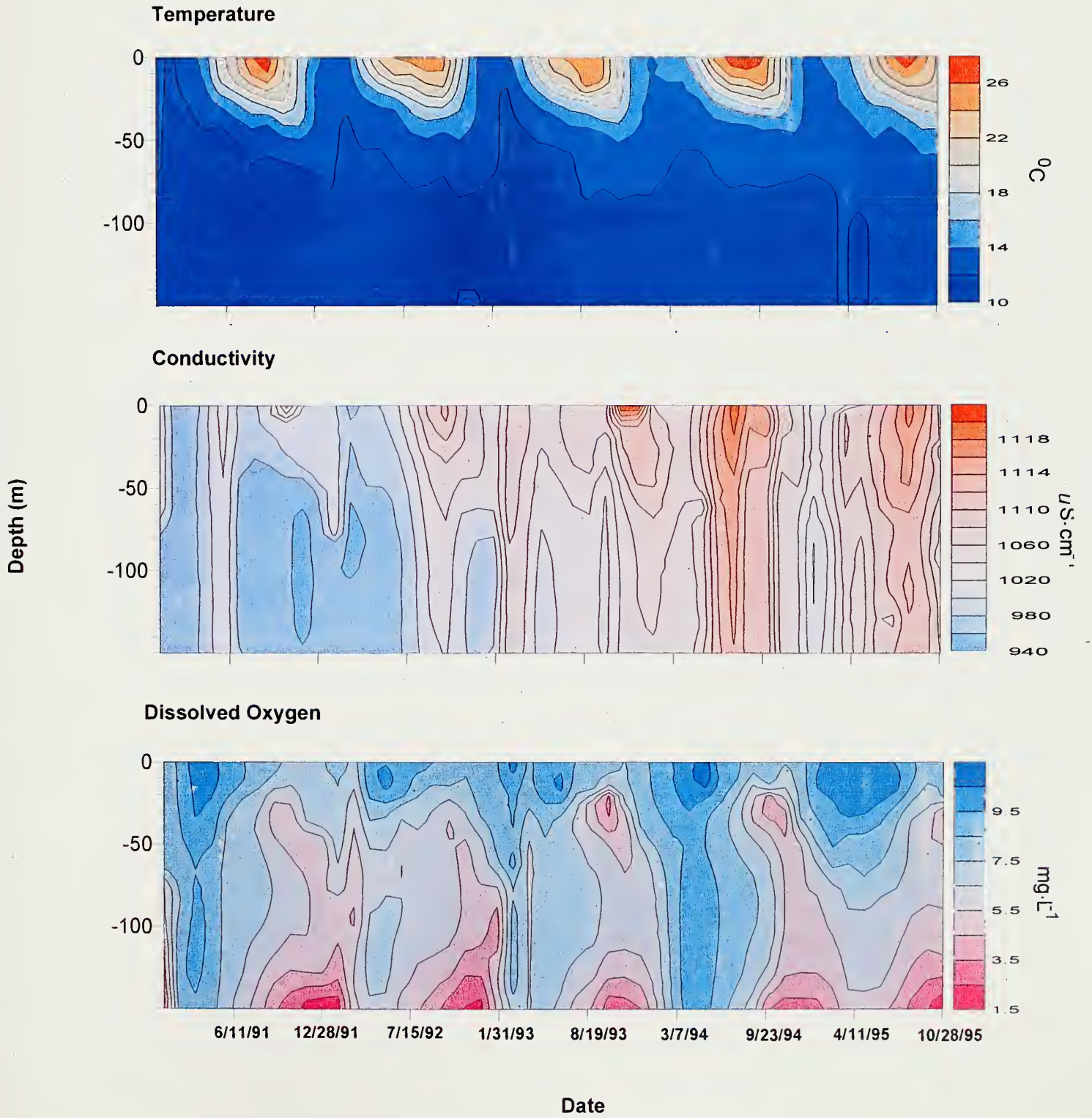

Temperature
0
-50
-100
26
22
18
14
10
°C
Conductivity
0
-50
-100
1118
1114
1110
1060
1020
980
940
uS·cm⁻¹
Dissolved Oxygen
0
-50
-100
9.5
7.5
5.5
3.5
1.5
mg·l⁻¹
6/11/91
12/28/91
7/15/92
1/31/93
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
Date
Depth (m)

Figure 5.-Time series isopleth data collected at LV05 (Las Vegas Bay) from May 1992 through November 1996.

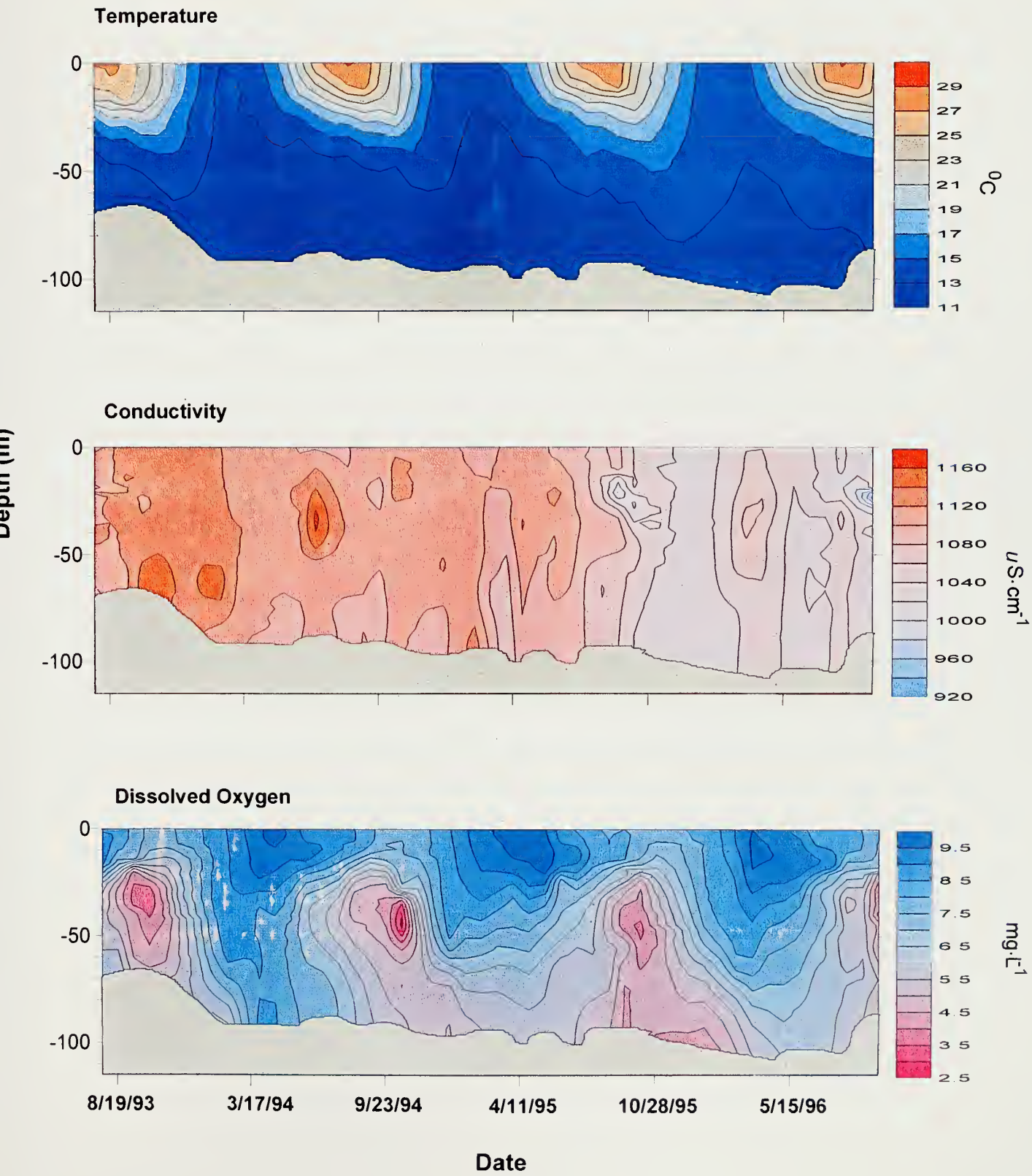

Temperature
0
-50
-100
29
27
25
23
21
19
17
15
13
11
°C
Conductivity
0
-50
-100
1160
1120
1080
1040
1000
960
920
uS·cm-1
Dissolved Oxygen
0
-50
-100
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
mg·L-1
Depth (m)
8/19/93
3/17/94
9/23/94
4/11/95
10/28/95
5/15/96
Date

Figure 6.-Time series isopleth data collected at LV17 (Hoover Dam) from January 1990 through October 1995.

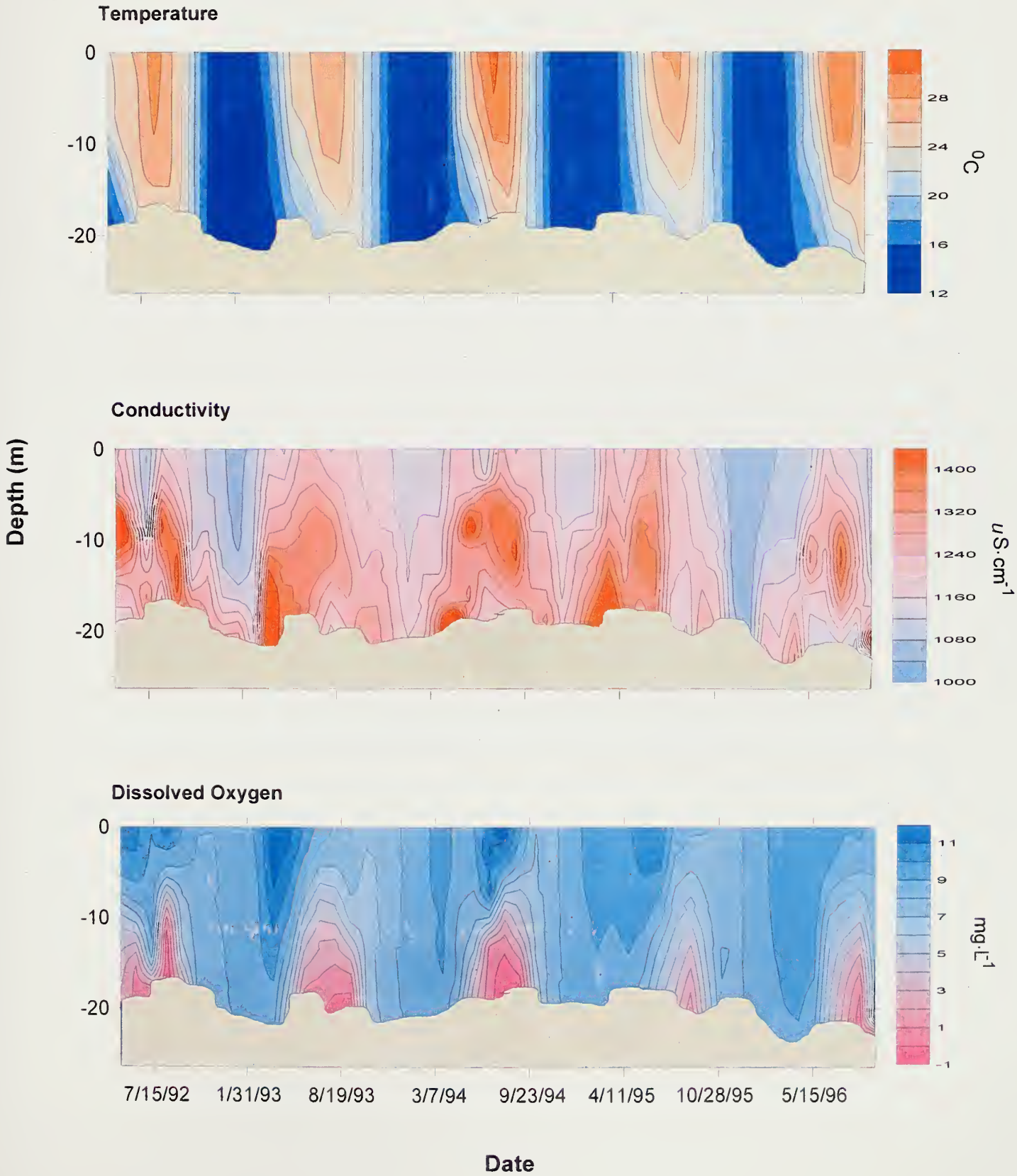
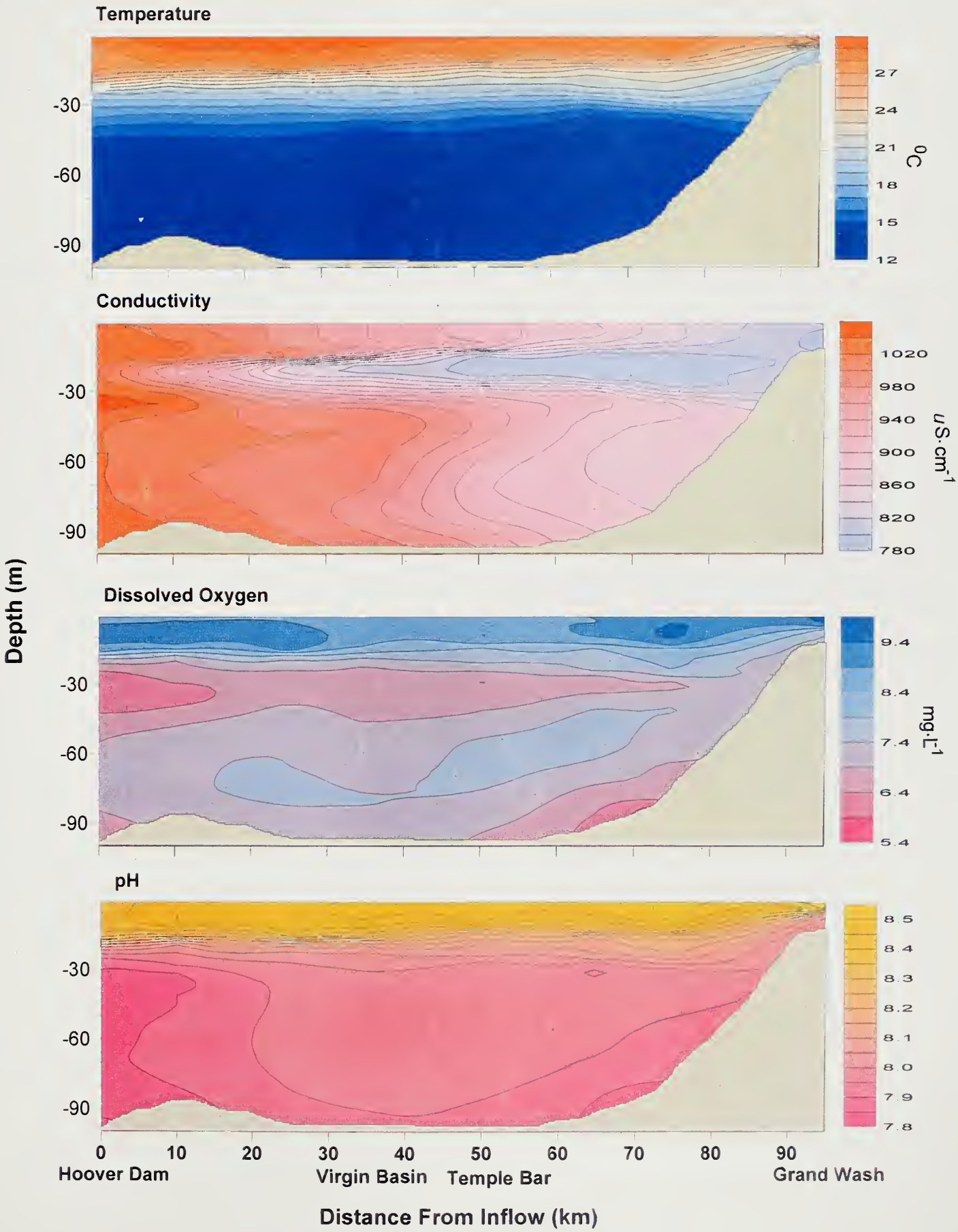

Temperature
0
-10
-20
28
24
20
16
12
°C
Conductivity
0
-10
-20
1400
1320
1240
1160
1080
1000
uS·cm-1
Dissolved Oxygen
0
-10
-20
11
9
7
5
3
1
-1
mg·L-1
7/15/92
1/31/93
8/19/93
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
Depth (m)
Date

Figure 7. -Isopleth description of temperature, specific conductance, dissolved oxygen concentration, and pH values based upon data collected from Grand Wash to Hoover Dam.


Temperature
27
24
21
18
15
12
°C
Conductivity
1020
980
940
900
860
820
780
uS·cm-1
Dissolved Oxygen
9.4
8.4
7.4
6.4
5.4
mg·L-1
pH
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
Depth (m)
-30
-60
-90
0
10
20
30
40
50
60
70
80
90
Hoover Dam
Virgin Basin
Temple Bar
Grand Wash
Distance From Inflow (km)